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# Possible human health risk of selected heavy metals' mobility from municipal waste compost amended agricultural soil

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**Use of organic compost in soil amendment in agricultural practice may tend to transfer heavy metals and can be a health concern. This study aims to investigate the possible mobilization of selected heavy metals from municipal compost amended soil. Experimental plots (250 m²) were divided into four equal portions and alternate portions were amended with municipal compost and left for 5 weeks. Soil physicochemical characteristics for compost, compost amended soil, and unamended soil were obtained by standard procedures, single extraction was obtained by diethylenetriamine penta acetic acid (DTPA) protocol, and the geochemical forms were obtained by Bureau Community of Reference (BCR) sequential extraction method. The extracts were analyzed using Atomic Absorption Spectrophotometer (Buck Scientific Model 210). In this study, the amendment of soil with compost resulted in significant changes in various physico-chemical properties, with notable percentage increases: pH (16.72%), electrical conductivity (EC, 1509.63%), organic carbon (OC, 100.24%), organic matter (OM, 24.43%), organic nitrogen (ON, 24.41%), potassium (K, 1950.63%), sodium (Na, 325.03%), calcium (Ca, 67.93%), and magnesium (Mg, 112.92%). Although, the concentrations of metals were marginally altered by amendments, the study has revealed soil amendment with organic compost a potential source of heavy metals in diet.**

**Key words:** Heavy metals, sequential extraction, mobility, municipal waste compost, agricultural soil, environmental health.

## INTRODUCTION

The concept of recycling municipal waste nutrients and organic materials into agricultural farms is both practical

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and advantageous (Ahmed et al., 2019). Compost, which is a mixture of organic waste materials including decayed flora and other organic matter, serves as a valuable source of organic soil for gardeners, supplying nutrients to crops and enhancing soil structure, fertility, and productivity (USDA, 2005). This practice is essential for effective organic waste disposal, a fundamental aspect of compost production. The primary objective of soil amendments is to improve soil fertility and increase crop productivity. Municipal derived-compost is rich in organic matter, contains essential plant nutrient, cheap and available, therefore it has been an alternative soil amendment (Pergola et al., 2018).

Lack of proper sorting of municipal waste prior to composting is a major route for heavy metal contamination. Their concentration differs largely depending on their sources, composting process, and geographical location (Sharma et al., 2019). Often times, present in municipal wastes are batteries, cigarette, metal scraps, electronic parts, computer parts, cosmetics, non-essential elements, persistent organic compound and/or microorganism which can contribute toxic metals into compost; this may be detrimental to animals, plants, and man when absorbed into food chain (Iwegbue et al., 2005). Their presence in high concentration can restrict the use of compost on agricultural land and has raised serious concern about the application of composts in relation to public health safety and thus its use to grow crops destined for human consumption (Lar and Usman, 2014). The mobility and availability of heavy metals in soil are controlled by adsorption and desorption characteristics of soils. The adsorption and desorption of heavy metals have been proven to be associated with soil properties, including pH, organic matter content, cation exchange capacity (CEC), oxidation-reduction status (Eh), clay minerals, calcium carbonate, Fe, and Mn oxides (Caporale and Violante, 2016). Among these soil properties, soil pH was found to play the most important role in determining metal distribution and mobility and eventually bioavailability. There is a direct correlation between soil pH and metal retention (Zeng et al., 2011). Heavy metal in food has been found to produce terminal diseases (Onakpa et al., 2018).

Due to the potential risks associated with the use of heavy metal-contaminated compost, many countries worldwide have established specific guidelines and standards for compost application in agricultural settings (Arora and Chauhan, 2021). Garnier et al. (2006) have emphasized the significance of understanding the fractions and chemical forms of metals in amended soil, as they play a crucial role in determining their potential remobilization, phytoavailability, and environmental impact. As a result, the primary objective of this research is to investigate the remobilization potential of selected heavy metals in agricultural soil amended with organic compost derived from municipal solid waste in Akure metropolis, Nigeria.

## MATERIALS AND METHODS

### Farm description

The study farm is located within the premises of Federal University of Technology Akure, Ondo State, Nigeria. It is a plain land with short trees and shrubs, with no record of any agricultural activities. The farm has an area of 250 m$^2$ (25 × 10 m) and located on longitude N 07° 17'59.8"; latitude of E 005° 08'03.4".

### Farm preparation and soil sampling

The experimental plot (250 m$^2$) used for the study was cleared and plough (30 cm) into 4 garden beds of 62.5 m$^2$ each. Alternate portions were amended with 3.75 × 50 kg compost fertilizer obtained from the Ondo State Waste Management Authority, Akure to give approximately 30 tonnes of compost/hectare of sandy clay loam soil recommended for vegetable farming (Pivato et al., 2014), while the other two alternate portions were left unamended (Figure 1). The study farm soil was mixed with the compost, up to a depth of 20 cm, left for 5 weeks for adequate compost-soil interaction (Setia et al., 2011) and then 5 points each were sampled from each segment; using systematic random sampling method, packed carefully into polythene bags and transported to the laboratory. In the laboratory, soil samples were mixed thoroughly, air-dried at room temperature in a dust free laboratory, disaggregated using agate mortal, sieved through 2.0 mm BS standard sieve and kept in clean polyethylene bag for analysis (Inengite et al., 2015).

### Soil analysis

#### Determination of soil physicochemical properties

pH and electrical conductivity were measured using the electrometry method (ASTM, 2018). Organic carbon content was determined with the Walkley-Black method (AOAC, 2009). Soil particle sizes were analyzed through the hydrometer method as described by Inengite et al. (2015). Additionally, exchangeable bases were extracted using a 1 M ammonium acetate solution, and the resulting supernatant was subjected to analysis for potassium (K) and sodium (Na) using a Flame Photometer as well as magnesium (Mg) and calcium (Ca) using an Atomic Absorption Spectrophotometer (Inengite et al., 2015).

#### Extraction of heavy metals using diethyleneamine tetrapenta acetic acid (DTPA)

Solutions (20 ml) of 0.005 M DTPA, 0.01 M TEA (triethanolamine), and 0.01 M CaCl$_2$ (2:1:1) were adjusted to pH 7.3 using 0.1 M HCl and added to 10 g of compost, amended, and unamended soil. The mixture was thereafter shaken for 2 h, filtered into 60 ml sample bottle and analysed using AAS for the selected heavy metals (Wei et al., 2011).

#### Sequential extraction of heavy metals analysis using Bureau Community of Reference (BCR) method

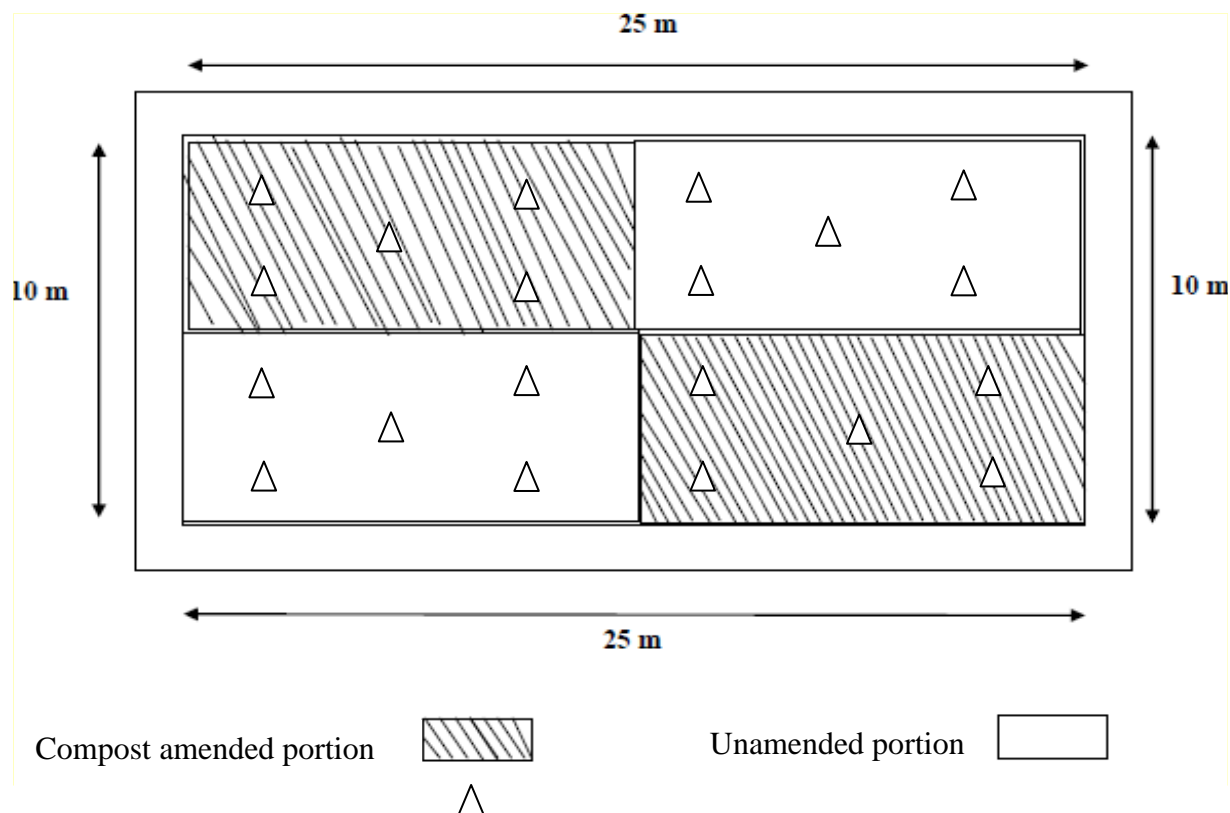A three step BCR sequential extraction procedure (Fernandez-

**Figure 1.** Farm sketch showing compost amended and unamended portion.

Ondono et al., 2017) was used to sequentially extract the heavy metals into their chemical form. The residue was treated with aqua regia as depicted in Figure 2.

**Statistical analysis**

Significant differences between concentrations of heavy metals in compost-amended and unamended soil as well as fraction 1 of BCR sequential extraction and DTPA single extraction were analyzed by ANOVA. Statistical significance was defined as $p < 0.05$.

**RESULTS AND DISCUSSION**

Table 1 presents the characteristics of the compost (CMP), compost-amended soil (CAS), and unamended soil (UAS). The pH of unamended soil, compost amended soil, and compost ranged between 5.68 and 9.07. The pH of the unamended soil and compost-amended soil is within most plants' optimum pH of 5.5 to 7.0 whereas that of compost is a little higher. Compost application has been known to increase soil pH thereby limiting the mobility of heavy metals (Beesley et al., 2010; Fanrong et al., 2011). Electrical conductivity increases from 44.67 µS/cm in UAS to 75.17 µS/cm in compost-amended soil. Organic carbon content was 37.5 g/kg in compost, this equally translated to higher organic carbon from 25.35 g/kg in UAS to 31.55 g/kg in compost-amended soil. Compost application on unamended soil recorded a percentage increase of 32.40% in soil organic carbon. C/N ratio has a value of 20.00 for compost which is marginal after application. The concentrations of exchangeable cations are Na (28.01 g/kg), Mg (47.27 g/kg), K (147.03 g/kg), and Ca (153.49 cmol/kg) for CAS and Na (6.59 g/kg), Mg (22.20 g/kg), K (7.17 g/kg), and Ca (91.40 g/kg) for unamended soil. The possible reason for the higher concentrations of exchangeable cations and organic matter in compost-amended soil could be related to the decomposition of organic material in municipal waste to release K, Na, Ca, and Mg into the soil and makes soil less susceptible to erosion, which is in line with the work of Fageria (2009).

Compost-amended soil and unamended soil fall into similar textural class of sandy clay loam.

DTPA is regarded as a more attractive alternative to acids or bases in metal extraction processes because they can form strong metal-ligand complexes and are thus highly effective in remediating heavy metal-contaminated soils (Malathi and Stalin, 2018). DTPA on the other hand is a single extraction method and it is
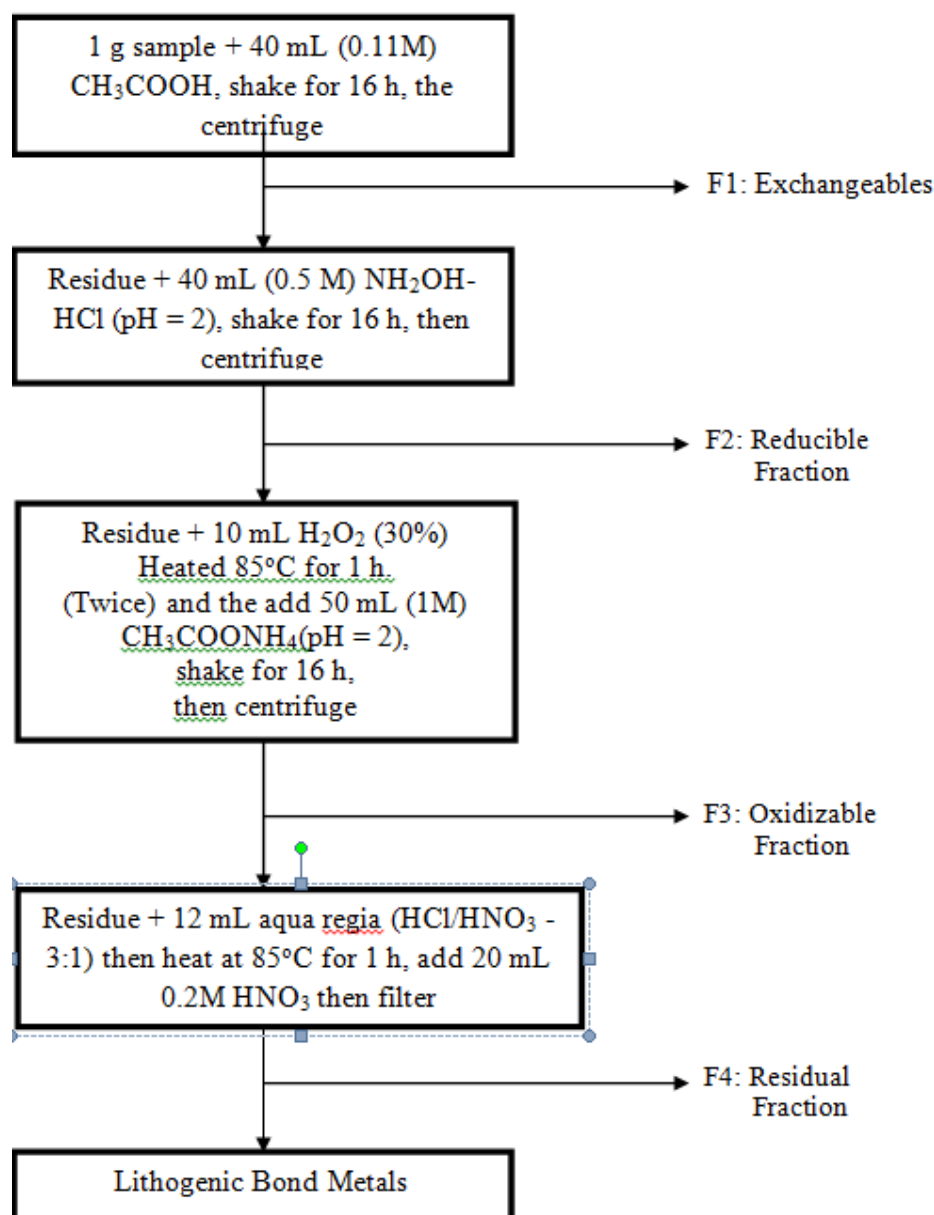
**Figure 2.** Flow chat of BCR sequential extraction method.

usually used to mimic plant nutrient uptake. The mean concentration of Fe, Cu, Zn, Pb, and Ni in UAS, CAS, and CMP using DTPA single extraction is presented in Table 2. For all metal, CMP has the highest extracted concentrations, followed by CAS. The concentration of the metals is in the following decreasing order: Fe > Zn > Cu > Ni > Pb, Fe > Zn > Ni > Cu > Pb, and Fe > Zn > Ni > Cu > Pb for UAS, CAS, and CMP, respectively. Fe had the highest concentration; next to it is Zn in UAS, CAS, and CMP while Pb is the least.

The chemical form and distribution of heavy metals in soil control the degree to which metal and their compound

are mobile, extractable, and phytoavailable. Heavy metals in soluble, carbonates, and exchangeable fractions tend to be more mobile possibly by lower soil pH and changes in redox potential (Shen et al., 2022). The most mobile metals are removed in the first fractions and continue in order of decreasing mobility during sequential extraction procedures.

Typically, metals of anthropogenic input tend to reside in this phase while metals found in the residual fractions are of natural origin from the parent rock (Ratuzny et al., 2009). In Table 3, F1 and F2 fractions contain significant quantities of heavy metals which can be phytoavailable or

**Table 1.** Mean value of physico-chemical parameters for compost, compost amended and unamended soil.

| Parameter | N | CMP | CAS | UAS |
|---|---|---|---|---|
| pH | 6 | 9.07 ± 0.06[b] | 6.63 ± 0.21[b] | 5.68 ± 0.41[a] |
| EC (µScm$^{-3}$) | 6 | 3003.33 ± 6.09[c] | 75.17 ± 5.42[b] | 44.67 ± 5.65[a] |
| SOC (g/kg) | 6 | 37.50 ± 0.15[c] | 31.55 ± 0.61[b] | 25.35 ± 0.46[a] |
| ON (g/kg) | 6 | 1.88 ± 0.01[c] | 1.58 ± 0.03[b] | 1.27 ± 0.02[a] |
| C:N | 6 | 19.95 ± 0.00[a] | 19.97 ± 0.01[a] | 19.96 ± 0.02[a] |
| Na (cmol/kg) | 6 | 357.93 ± 1.72[a] | 28.01 ± 0.47[a] | 6.59 ± 1.23[a] |
| Mg (cmol/kg) | 6 | 153.52 ± 1.28[c] | 47.27 ± 1.17[b] | 22.20 ± 4.12[a] |
| K (cmol/kg) | 6 | 2652.62 ± 8.37[c] | 147.03 ± 1.10[b] | 7.17 ± 1.69[a] |
| Ca (cmol/kg) | 6 | 205.63 ± 1.31[c] | 153.49 ± 2.30[b] | 91.40 ± 1.89[a] |
| % Clay | 6 | - | 24.50 ± 1.06[a] | 22.50 ± 1.34[a] |
| % Silt | 6 | -- | 25.00 ± 1.14[b] | 18.00 ± 3.43[a] |
| % Sand | 6 | | 50.50 ± 3.31[a] | 59.50 ± 1.34[a] |

UAS: Unamended soil; CAS: compost amended soil; CMP: compost; N: number of replicates = 3. Alphabets in superscripts denote the homogenous groupings from ANOVA and Duncan Multiple Range test.

**Table 2.** Heavy metal concentration (mg/kg) in DTPA extraction protocol.

| Metal | CMP | CAS | UAS |
|---|---|---|---|
| | Mean ± SD | Mean ± SD | Mean ± SD |
| Fe | 74.73[c] ± 1.60 | 44.13[b] ± 0.53 | 33.42[a] ± 0.33 |
| Cu | 11.77[c] ± 0.62 | 5.78[b] ± 0.02 | 0.41[a] ± 0.00 |
| Zn | 13.43[c] ± 1.92 | 10.85[b] ± 0.01 | 0.83[a] ± 0.00 |
| Pb | 0.62[b] ± 0.00 | 0.19[a] ± 0.00 | 0.00 ± 0.00 |
| Ni | 12.31[c] ± 0.02 | 9.51[b] ± 0.01 | 0.30[a] ± 0.00 |

UAS: Unamended soil; CAS: compost amended soil; CMP: compost; N: number of replicates = 3. Alphabets in superscripts denote the homogenous groupings from ANOVA and Duncan Multiple Range test.

leached during changes in environmental conditions. They could pose threat to groundwater quality as well as plant absorption. Acidic environment also enhances the mobility of metal in the environment in this group; therefore, those metals found in F2 fraction are very sensitive to pH changes and could be leached at lower pH (Zheng et al., 2007).

In Table 3, the concentrations of Fe, Zn, and Ni in CMP, CAS, and UAS, as obtained by BCR extraction, exhibits the following order: F1 > F2 > F3 > Residual for Fe, F1 > Residual > F2 > F3 for Zn, and F1 > Residual > F3 > F2 for Ni. The results indicate that Fe, Zn, and Ni were released in easily mobilized forms (F1) at all stages of the sequential extraction for CMP, CAS, and UAS, consistent with the findings of Nomeda et al. (2008). This suggests that Fe, Zn, and Ni in the F1 fraction are readily available for plant uptake (Lee et al., 2015) and may have anthropogenic sources originating from the compost (Ratuzny et al., 2009). Aside from Fe, which is more

abundant in the Earth's crust, sources of Ni and Zn in the environment include mining activities, combustion of coal, diesel and fuel oil, sewage and waste incineration, and tobacco smoking. These sources are commonly associated with municipal solid waste, making them potential contributors to the presence of Ni and Zn in compost.

A larger portion of Cu and Pb was found to be associated in the F4 (residual) which is the fraction more resistant to extraction. This could be that a larger portion of Cu and Pb occurs naturally in the parent material, that is, in the agricultural soil used in this study (Haroun et al., 2009). The concentration of Cu and Pb in UAS, CAS, and CMP obtained by BCR extraction follows this order: Residual > F 1 > F 2 > F 3. This result is similar to that of Li et al. (2012) who found percentages of Pb in soil fractions decreasing in the order of Residual > F 1 > F 3 > F 2. Metals contained in the crystal lattices of the minerals or residual phase are strongly bound and

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**Table 3.** Heavy metal concentration (mg/kg) in compost, compost-amended soil and unamended soil in BCR Sequential Extraction.

| Metal | F1 | | | F2 | | | F3 | | | Residual | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CMP | CAS | UAS | CMP | CAS | UAS | CMP | CAS | UAS | CMP | CAS | UAS |
| Fe | 50.15[b] ± 0.04 | 46.24[b] ± 0.04 | 30.24[a] ± 0.05 | 34.10[a] ± 0.13 | 36.83[c] ± 1.35 | 36.34[b] ± 2.40 | 24.99[a] ± 1.09 | 29.75[a] ± 1.33 | 29.39[a] ± 0.52 | 10.49[a] ± 40.4 | 20.04[b] ± 2.28 | 19.26[b] ± 1.67 |
| Cu | 8.40[b] ± 0.03 | 5.98[b] ± 0.00 | 0.36[a] ± 0.00 | 2.30[c] ± 0.01 | 1.12[b] ± 0.01 | 0.04[a] ± 0.00 | 1.58[b] ± 0.00 | 1.09[b] ± 0.01 | 0.02[a] ± 0.00 | 7.16[b] ± 0.00 | 3.81[b] ± 0.01 | 0.30[a] ± 0.00 |
| Zn | 12.71[c] ± 0.07 | 8.55[b] ± 0.05 | 0.90[a] ± 0.00 | 3.17[b] ± 0.74 | 1.93[b] ± 0.07 | 0.20[a] ± 0.00 | 2.31[b] ± 0.69 | 1.31[b] ± 0.08 | 0.17[a] ± 0.05 | 5.91[c] ± 0.12 | 2.76[b] ± 0.02 | 0.74[a] ± 0.05 |
| Pb | 0.31[b] ± 0.00 | 0.12[b] ± 0.00 | 0.00[b] ± 0.00 | 0.002[a] ± 0.00 | 0.01[a] ± 0.00 | 0.00[a] ± 0.00 | 0.03[a] ± 0.00 | 0.01[a] ± 0.00 | 0.00[a] ± 0.00 | 0.42[b] ± 0.00 | 0.14[b] ± 0.00 | 0.00[a] ± 0.00 |
| Ni | 9.20[b] ± 0.00 | 7.10[b] ± 0.00 | 0.21[b] ± 0.00 | 0.50[b] ± 0.00 | 0.20[b] ± 0.00 | 0.04[a] ± 0.00 | 0.80[b] ± 0.00 | 0.70[b] ± 0.00 | 0.05[a] ± 0.00 | 4.94[c] ± 0.20 | 3.11[b] ± 0.20 | 0.45[a] ± 0.01 |

F1: Soil water + Carbonates + Exchangeables, F2: Iron/Manganese oxyhydroxides, F3: Organic matter + Sulphides, Residual: Total digestion (Remaining + silicate bound metals). Alphabets in superscripts denote the homogenous groupings from ANOVA and Duncan Multiple Range test.

consequently unavailable to the plants (Chao et al., 2007; Zhou et al., 2007). Despite this observation, their extraction in F1 fractions is the second largest and could indicate a mixed origin for these metals (that is, both anthropogenic and lithogenic).

Generally, for all metal under study, CMP exhibits the highest concentration of Fe, Cu, Zn, Pb, and Ni followed by CAS and then UAS. This is an indication that compost rich in heavy metal contamination may hold the possibility of metal transferring into soil and eventually to plant. This study has demonstrated these findings due to the relatively high heavy metal content in the compost and its potential remobilization in amended agricultural soil. It is worth noting that, although the levels of metals observed in CAS were below the permissible limits set by the WHO (2014) and the allowable metal values for compost in the USA (biosolids) and EU (Brinton, 2000).

The mean concentration of Zn, Pb, and Ni in DTPA single extraction method was higher than F1 of BCR sequential extraction method in UAS, CAS, and CMP. The same was also observed for Fe and Cu in UAS and CMP with the exemption of CAS; where the concentration of Fe and Cu in F1 of BCR sequential extraction method was higher

than DTPA single extraction method. The results obtained agree with the observation of McLaughlin et al. (2000) that DTPA may over-estimate plant-available metals. F1 fraction of the BCR sequential extraction method is the sum of the exchangeable and carbonate fractions and the selected heavy metals contribute significantly to this fraction. This fraction is bioavailable and can easily be leached during changes in environmental conditions. They therefore, pose threat to groundwater quality and plant absorption.

## Conclusion

Municipally derived compost can offer cost-effective and readily available options, being rich in organic matter and essential nutrients. Amending soil with compost brings significant alterations to its physico-chemical properties and, to a lesser extent, the heavy metal content, including their distribution within the compost-amended soil. It is important to note that adding compost to soil leads to elevated concentrations of heavy metals in all BCR fractions. However, the behavior and chemistry of these metals may be significantly influenced by soil mineralogy. The

application of compost has resulted in increased concentrations of Fe, Cu, Zn, Pb, and Ni across all fractions. Notably, the mobility of Fe, Cu, Zn, and Ni has increased, and they are predominantly found in the more available fractions, specifically F1 (water-soluble, exchangeable, and carbonates). The use of composted materials as organic fertilizer for soil amendment in vegetable gardens could potentially lead to metal pollution in backyard vegetable farming. As such, it is strongly recommended that the composting process should include rigorous sorting and the application of compost should be considered only when essential.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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## REFERENCES

Association of Official Analytical Chemists (AOAC) (2009). Official Method of Analysis, 25th Edition, Association of Official Analytical Chemists, Washington DC, USA. P 98.

Ahmed M, Ahmad S, Hassan F, Qadir G, Hayat R, Shaheen FA, Raza MA (2019). Innovative Processes and Technologies for Nutrient Recovery from Wastes: A Comprehensive Review. Sustainability 11(18):4938.

Arora NK, Chauhan R (2021). Heavy metal toxicity and sustainable interventions for their decontamination. Environmental Sustainability 4:1-3.

ASTM (2018). Standard Test Methods for pH of Water, ASTM-D1293-18. Available at: https://www.astm.org/d1293-18.html

Beesley LE, Jiménez M, Gomez-Eyles JL (2010). Effects of Biochar and Greenwaste Compost Amendments on Mobility, Bioavailability and Toxicity of Inorganic and Organic Contaminants in a Multi-Element Polluted Soil. Environmental Pollution 158:2282-2287.

Brinton WF (2000). Compost Quality Standards and Guidelines. Final Report by Woods End Research Laboratory, Inc to New York State Association of Recyclers, USA 42 p.

Caporale AG, Violante A (2016). Chemical Processes Affecting the Mobility of Heavy Metals and Metalloids in Soil Environments. Current Pollution Reports 2:15-27.

Chao W, Xiao-Chen L, Li-Min Z, Pei-Fang W, Zhi-Yong G (2007). Pb, Cu, Zn and Ni concentrations in vegetables in relation to their extractable fractions in soils in suburban areas of Nanjing, China. Polish Journal of Environmental Studies 16:199-207.

Fageria NK (2009). The Use of Nutrient in Crop Plants. Taylor and Francis group, CRC Press, New York, USA. pp. 32-136.

Fanrong Z, Shafaqat A, Haitao Z, Younan O, Boyin Q, Feibo W, Guoping Z (2011). The Influence of pH and Organic Matter Content in Paddy Soil on Heavy Metal Availability and Their Uptake by Rice Plants. Environmental Pollution 159(1):84-91.

Fernandez-Ondono E, Bacchetta G, Lallena AM, Navarro FB, Ortiz I, Jiménez MN (2017.) Use of BCR sequential extraction procedures for soils and plant metal transfer predictions in contaminated mine tailings in Sardinia. Journal of Geochemical Exploration 172:133-141.

Garnier J, Quantin C, Martins ES, Becquer T (2006). Solid Speciation and Availability of Chromium in Ultramafic Soils from Niquelandia. Brazil. Journal of Geochemical Exploration 88:206-209.

Inengite AK, Abasi CY, Walter C (2015). Application of Pollution Indices for the Assessment of Heavy Metal Pollution in Flood Impacted Soil. International Resource Journal of Pure and Applied Chemistry 8(3):175-189.

Iwegbue CMA, Nwajei GE, Osakwe SA (2005). Recycling Waste in Agriculture: Efficacy of Composting in Ameliorating Trace Metal Availability and Soil Borne Pathogens. European Journal of Science and Research 11(3):572-577.

Lar AU, Usman S (2014). Environmental Risk Assessment of Heavy Metals Content of Municipal Solid Waste used as Organic Fertilizer in Vegetable Gardens on the Jos Plateau, Nigeria. American Journal of Environmental Protection 3(6-2):1-13.

Lee PK, Choi BY, Kang MJ (2015). Assessment of mobility and bio-availability of heavy metals in dry depositions of Asian dust and implications for environmental risk. Chemosphere 119:1411-1421.

Malathi P, Stalin P (2018). Evaluation of AB - DTPA Extractant for Multinutrients Extraction in Soils. International Journal of Current Microbiology and Applied Science 7(03):1192-1205.

McLaughlin MJ, Zarcinas BA, Stevens DP, Cook N (2000). Soil Testing for Heavy Metals. Communications in Soil Science and Plant Analysis 31:1661-1700.

Nomeda S, Valdas P, Chen Shen-Yi, Lin Jih-Gaw (2008). Variations of metal distribution in sewage sludge composting. Waste Management 28:1637-1644.

Onakpa M, Anoka N, Ogbureke K (2018). A Review of Heavy Metal Contamination of Food Crops in Nigeria. Annals of Global Health 84:488.

Pergola M, Persiani A, Palese AM, Meo VD, Pastore V, D'Adamo C, Celano G (2018). Composting: The Way for a Sustainable Agriculture. Applied Soil Ecology 123:744-750.

Pivato A, Raga R, Vanin S, Rossi M (2014). Assessment of Compost Quality for Its Environmentally Safe use by Means of an Ecotoxicological Test on a Soil Organism. Journal of Material Cycles and Waste Management 16:763-774.

Ratuzny T, Gong Z, Wilke BM (2009). Total Concentrations and Speciation of Heavy Metals in Soils of the Shenyang Zhangshi Irrigation Area, China. Environmental Monitoring and Assessment 156:171-180.

Setia R, Marschner P, Baldock J, Chittleborough D, Verma V (2011). Relationship between Carbon-Dioxide Emission and Soil Properties in Salt Affected Landscape. Soil Biology and Biochemistry 43:667-674.

Sharma B, Vaish B, Monika, Singh UK, Singh P, Singh RP (2019). Recycling of Organic Wastes in Agriculture: An Environmental Perspective. International Journal of Environmental Research 13:409-429.

Shen Q, Xiang J, Zhang M (2022). Distribution and Chemical Speciation of Heavy Metals in Various Size Fractions of Aggregates from Zonal Soils. International Journal of Environmental Analytical Chemistry 102(16):4272-4287.

USDA (2005). U.S. Department of Agriculture, Agricultural Research Service. USDA National Nutrient Database of Standard Reference, Release 18:43-47.

Wei J, Tao T, Zhiming L (2011). Removal of Heavy Metal from Contaminated Soil with Chelating Agents. Open Journal of Soil Science 1:70-76.

Zeng F, Ali S, Zhang H, Ouyang Y, Qiu B, Wu F, Zhang G (2011). The influence of pH and organic matter content in paddy soil on heavy metal availability and their uptake by rice plants. Environmental Pollution 159(1):84-91.

Zheng GD, Chen TB, Gao D, Luo W (2007). Stabilization of Nickel and Chromium in Sewage Sludge during Aerobic Composting. Journal of Hazardous Materials 142:216-221.

Zhou JM, Dang Z, Cai MF, Liu CQ (2007). Soil Heavy Metal Pollution Around the Dabaoshan Mine, Guangdong Province, China. Pedosphere 17(5):588-594.